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Technical and tactical skills related to performance levels in tennis: A systematic review

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ABSTRACT

The aim of this systematic review is to provide an overview of outcome measures and instruments identified in the literature for examining technical and tactical skills in tennis related to performance levels. Such instruments can be used to identify talent or the specific skill development training needs of particular players. Searches for this review were conducted using the *PubMed*, *Web of Science*, and *PsycInfo* databases. Out of 733 publications identified through these searches, 40 articles were considered relevant and included in this study. They were divided into three categories: (1) technical skills, (2) tactical skills and (3) integrated technical and tactical skills. There was strong evidence that technical skills (ball velocity and to a lesser extent ball accuracy) and tactical skills (decision making, anticipation, tactical knowledge and visual search strategies) differed among players according to their performance levels. However, integrated measurement of these skills is required, because winning a point largely hinges on a tactical decision to perform a particular stroke (i.e., technical execution). Therefore, future research should focus on examining the relationship between these skills and tennis performance and on the development of integrated methods for measuring these skills.

ARTICLE HISTORY

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KEYWORDS

Motor skills; athletic performance; speed-accuracy trade-off; decision making; anticipation

Introduction

Performance in sports results from the interaction of multiple factors (Newell, 1986). According to Newell's constraints-led approach, motor performance is influenced by interactions of the task at hand, the environment and the concerned individual. This approach has been elaborated within the model for talent identification and development in sports (Elferink-Gemser, Visscher, Lemmink, & Mulder, 2007). In this model, multidimensional performance characteristics are seen to affect sports performance. Specifically in tennis, performance is multidimensional, as revealed by the integration of anthropometrical, physiological, technical, tactical and psychological characteristics that all influence (future) performance (Elferink-Gemser, Visscher, Lemmink, & Mulder, 2004; Kovacs, 2007). Anthropometrical characteristics include factors such as height and weight (Sanchez-Muñoz, Sanz, & Zabala, 2007), whereas physiological characteristics include speed, agility, strength and endurance (Kovacs, 2007). These characteristics are considered to be general ones, because they apply to many sports and not exclusively to tennis (Baker, Cote, & Abernethy, 2003). This is also true for psychological skills, such as motivation, attention and arousal regulation, all of which are important performative elements in a variety of sports (Birrer & Morgan, 2010). By contrast, technical and tactical skills are more specific to particular sports (Fernandez-Fernandez et al., 2011). In tennis, they include factors like ball and racket handling, recognition of on-court tactical situations and appropriate decision making (MacCurdy, 2006). Technical skills in tennis

are mostly demonstrated through serves and groundstrokes. Two important variables of a serve include ball velocity and the percentage of correct first serves (Knudson, Noffal, Bahamonde, Bauer, & Blackwell, 2004). Tactical skills are defined as knowledge about in-game adaptations and decision-making activities on court (Elferink-Gemser, Kannekens, Lyons, Tromp, & Visscher, 2010). Compared with other factors, the combination of technical and tactical skills is more likely to differentiate players whose performance levels differ (Vaeyens, Lenoir, Williams, & Philippaerts, 2008). This hypothesis is supported by the findings of other studies, suggesting that these skills may be important for identifying talent and for sporting prowess (Meylan, Cronin, Oliver, & Hughes, 2010; Strecker, Foster, & Pascoe, 2011).

A player's ball velocity and success rate, combined with ball accuracy, are key determinants of his or her stroke quality (Landlinger, Stöggel, Lindinger, Wagner, & Müller, 2012; Strecker et al., 2011; Vergauwen, Madou, & Behets, 2004). The key role of ball velocity in relation to tennis performance is supported by the findings of Ulbricht, Fernandez-Fernandez, Mendez-Villanueva, and Ferrauti (2016), who measured correlations between players' physical qualities and tennis performance. Their findings revealed that serve velocity was most strongly correlated with players' rankings across all age categories, indicating the importance of ball velocity in tennis performance. This is demonstrated by the ability of professional tennis players to direct their strokes both forcefully and accurately to any intended location on the court (Elliott, Reid,

& Crespo, 2009). An accurate stroke that lacks a high ball velocity benefits the opponent, giving this player more time to prepare. Therefore, the combination of ball velocity and accuracy is essential for almost every successful stroke. Accordingly, this review focused on ball velocity and ball accuracy as outcome measures of technical skills. These technical skills are also required for the execution of appropriate tactics. Thus, the quality of tactical skills may also improve with the development of technical skills (Wang, Liu, & Chen, 2013).

Expert players exhibit advanced decision-making skills. This is because the characteristics of knowledge structures that support motor performance gradually change over time, with a progressive increase in the degree of implicit (unconscious) control and a corresponding reduction in the degree of explicit (conscious) control (Masters, Poolton, Maxwell, & Raab, 2008). Declarative knowledge or “knowing what to do”, which is consciously accessible, can be distinguished from procedural knowledge that relates to “doing it”, which is implicit. The relationship between the two types of knowledge is such that knowing facilitates doing and vice versa (Williams & Davids, 1995). The ability of experts to apply complex visual information is essential for anticipating future events and is widely considered to be one of the core skills associated with motor performance (Abernethy, Gill, Parks, & Packer, 2001; Williams, Ward, Knowles, & Smeeton, 2002).

Previous studies have demonstrated that both technical and tactical skills are important for reaching the top ranks in tennis (MacCurdy, 2006; Strecker et al., 2011). The continued interplay of technical and tactical skills assumes critical importance in the winning of every point in a match. Technique plays a functional role in achieving a tactical goal. For example, if the tactical goal is to make the opponent move outside of the court, a short ball cross-court strategy entailing a certain ball velocity is required. Moreover, players’ own positions prompt another technical execution. When a player is playing defensively, high and deep ball hits are useful for gaining time and covering the court more effectively. These examples illustrate how the interplay of technical and tactical skills occurs in practice. However, few studies have examined how these skills relate to performance levels. Moreover, little is known about the effects of specific technical and tactical skills on performance. Additionally, there is a need to explore practical solutions in relation to performance analyses, because few coaches and instructors use tools for assessing technical and tactical skills with the aim of improving performance levels in tennis. Therefore, the purpose of this review is to provide an overview of outcome measures and instruments identified in the literature for examining technical and tactical skills in tennis related to performance levels. Furthermore, recommendations are offered on the analysis of these skills in tennis.

Methods

The *PubMed*, *Web of Science*, and *PsycInfo* databases were used to search for articles that contained the following terms:

- (1) Tennis AND (techni* OR accuracy OR velocity OR speed OR precision) AND (serv* OR groundstroke OR forehand

OR backhand) AND (performance OR level OR expertise OR elite) NOT table.

- (2) Tennis AND (tactic* OR knowledge OR decision OR anticipation OR declarative OR procedural) AND (performance OR level OR expertise OR elite) NOT table.

The following inclusion criteria were used to select articles for this review: English language content, studies focusing on sports-specific skills applied in tennis (i.e., technical and tactical skills), comparative studies of tennis players with different performance levels and original articles. The exclusion criteria applied in the review were studies on participants with health problems, studies focusing solely on kinematics and intervention studies.

Studies on participants with health problems were excluded, because an objective of this review was to acquire knowledge about the technical and tactical skills of players whose health status was not compromised. Studies that focused purely on kinematics were excluded, because this review targeted outcome measures of technical and tactical skills rather than the mechanisms underlying these skills. Last, intervention studies were excluded, because it is difficult to interpret the effect of an intervention.

Articles were initially analysed based on the inclusion criteria. Subsequently, the articles were evaluated based on the exclusion criteria. The steps used in the systematic search resulted in the identification of 40 relevant articles for further analysis (Figure 1).

The quality of the applied methodology in the included articles was assessed using the Critical Review Form – Qualitative Studies (Law et al., 1998). This tool can be used to evaluate many types of qualitative studies. This method was applied to assess each article according to the following categories: study purpose, literature background, study design, sample, outcomes, data analysis methods, results, conclusions and implications for future research (see the note below Table 1). These questions were assigned a score of either 1 (meet the criteria) or 0 (do not meet the criteria). The seventh and eighth questions were exceptional, as a NR (not registered) score could also be assigned to articles. A NR score indicated that no information was available on the reliability or validity of the instruments used in this systematic review. For the fifth question, articles reporting on studies with a sample size of at least 21 were assigned a score of 1, because this was the number required to obtain a statistical power of .80 or greater for detecting a large (one-tailed) difference at a 5% level of significance (Onwuegbuzie & Leech, 2005). The scores obtained for the 14 questions were summed for each article, with the NR score counted as 0. Table 1 shows the methodological quality of the reviewed studies. A total score below seven indicated low quality, a total score between seven and ten points indicated that the quality was good and a total score of 11 points or higher indicated high quality (van der Fels et al., 2015). Two researchers assessed the methodological quality of the included articles independently of one another. In less than 5% of all cases the researchers disagreed regarding scores. They discussed the disagreements and reached a consensus in all cases.

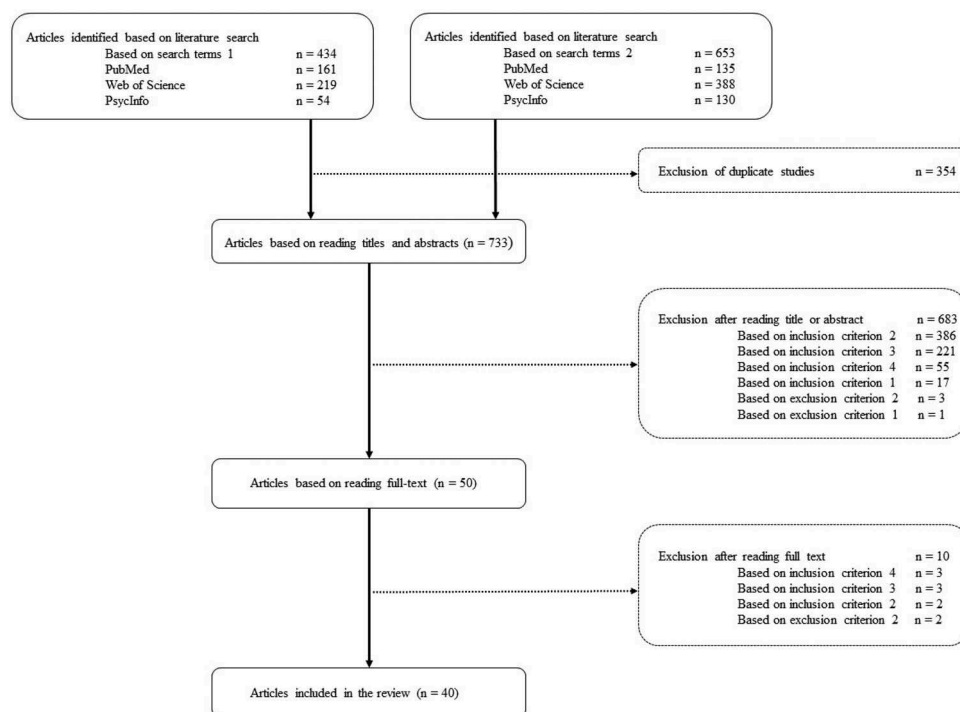


Figure 1. Stages adopted in the systematic selection of articles measuring technical and/or tactical skills in tennis players with different levels of performance.

Studies that satisfied certain conditions, discussed below, were considered to demonstrate one of four categories of evidence of the relationship between knowledge of technical and tactical skills and performance levels. Consistent results, reported by at least three studies of high methodological quality, were ranked as “strong evidence”. Alternatively, consistent results reported by 66% of more than four studies, with no more than 25% of these studies reporting conflicting results, indicated strong evidence. Consistent findings presented by two out of three studies, or reported by at least two high or good quality studies were interpreted as “weak evidence”. Inconsistent results reported by low or moderate quality studies, or by fewer studies of any quality were indicative of “insufficient evidence”. Last, “no evidence” was considered to be demonstrated when only one study was available.

Articles were divided into three categories: (1) technical skills ($n = 9$), (2) tactical skills ($n = 27$) and (3) technical and tactical skills ($n = 4$). Technical skills comprised the ball velocity, ball accuracy, efficiency, success rates and percentage errors of players. Tactical skills comprised anticipatory and decision-making skills, tactical knowledge and visual search strategies. Studies that assessed technical as well as tactical skills examined at least one aspect of each of the two skill types.

The subjects in the studies included in the review were classified as professionals, advanced players, intermediate players or novices according to their performance levels described in the studies. Players were defined as professionals if they had a position in the ranking lists of the Women’s Tennis Association or of the Association of Tennis Professionals or an International Tennis Number (ITN) of 1. Players were defined as advanced if they had a national ranking or an ITN ranging between 2 and 4. Players were defined

as intermediate if they had competitive tennis experience, at least 5 years of tennis experience or an ITN of 5 or 6. Players who were beginners, had no competitive tennis experience or had ITNs ranging between 7 and 10.1 were defined as novices.

Results

Table 2 shows the study authors; number, sex, age, performance level and tennis experience of subjects; measures of technical and tactical skills; and results reported in the 40 articles included in the review. Nine studies were included in the technical skills category (Girard, Micallef, & Millet, 2005, 2007; Kolman, Huijgen, Kramer, Elferink-Gemser, & Visscher, 2017; Landlinger et al., 2012; Lyons, Al Nakeeb, Hankey, & Nevill, 2013; Martin, Bideau, Ropars, Delamarche, & Kulpa, 2014; Söğüt, 2017; Vergauwen et al., 2004; Vergauwen, Spaepen, Lefevre, & Hespel, 1998). Five of these studies were of high methodological quality and four were of good methodological quality. There was strong evidence that ball velocity produced in serves and/or groundstrokes differentiates professionals from advanced players and advanced players from intermediate players and novices (Girard et al., 2005, 2007; Kolman et al., 2017; Landlinger et al., 2012; Martin et al., 2014; Söğüt, 2017; Vergauwen et al., 1998, 2004). The findings of Landlinger et al. (2012) and Vergauwen et al. (1998) showed higher ball velocities produced by forehand strokes compared with backhand strokes. However, no statistical tests were performed to confirm these visible differences.

There was weak evidence for greater accuracy of ball placement among advanced players compared with players demonstrating lower performance levels (Girard et al., 2005; Kolman et al., 2017; Lyons et al., 2013; Vergauwen et al., 2004).

Table 1. Methodological quality of the reviewed articles.^a

| Author (year)* | Question number ^b | | | | | | | | | | | | | | Total |
|-------------------------------|------------------------------|---|---|---|---|---|----|----|---|----|----|----|----|----|-------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | |
| Balser et al. (2014) | 1 | 1 | 1 | 1 | 0 | 1 | NR | NR | 1 | 1 | 0 | 1 | 0 | 1 | 9 |
| Buckolz et al. (1988) | 1 | 1 | 1 | 0 | 1 | 0 | NR | NR | 1 | 1 | 0 | 1 | 1 | 0 | 8 |
| Cañal-Bruland et al. (2011) | 1 | 1 | 1 | 1 | 0 | 1 | NR | NR | 1 | 1 | 0 | 1 | 1 | 1 | 10 |
| Cocks et al. (2016) | 1 | 1 | 1 | 1 | 0 | 1 | NR | NR | 1 | 1 | 0 | 1 | 1 | 0 | 9 |
| Del Villar et al. (2007) | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 10 |
| Farrow and Abernethy (2003) | 1 | 1 | 1 | 1 | 0 | 0 | NR | NR | 1 | 1 | 0 | 1 | 0 | 0 | 7 |
| Farrow et al. (2005) | 1 | 1 | 1 | 1 | 0 | 1 | NR | NR | 1 | 1 | 0 | 1 | 1 | 1 | 10 |
| García-González et al. (2012) | 1 | 1 | 1 | 1 | 0 | 1 | 1 | NR | 1 | 1 | 1 | 1 | 0 | 0 | 10 |
| Girard et al. (2005) | 1 | 1 | 1 | 1 | 0 | 1 | NR | NR | 1 | 1 | 1 | 1 | 0 | 0 | 9 |
| Girard et al. (2007) | 1 | 1 | 1 | 1 | 0 | 1 | NR | NR | 1 | 1 | 1 | 1 | 1 | 0 | 10 |
| Goulet et al. (1989) | 1 | 1 | 1 | 0 | 0 | 0 | 1 | NR | 1 | 1 | 1 | 1 | 0 | 0 | 8 |
| Huys et al. (2008) | 1 | 1 | 1 | 1 | 0 | 1 | NR | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 10 |
| Jackson and Mogan (2007) | 1 | 1 | 1 | 1 | 0 | 1 | 1 | NR | 1 | 1 | 1 | 1 | 1 | 1 | 12 |
| Kolman et al. (2017) | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| Landlinger et al. (2012) | 1 | 1 | 1 | 1 | 0 | 1 | NR | NR | 1 | 1 | 1 | 1 | 1 | 1 | 11 |
| Loffing and Hagemann (2014) | 1 | 1 | 1 | 1 | 1 | 1 | NR | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| Loffing et al. (2011) | 1 | 1 | 1 | 1 | 1 | 0 | NR | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 10 |
| Lyons et al. (2013) | 1 | 1 | 1 | 1 | 0 | 1 | NR | NR | 1 | 1 | 1 | 1 | 1 | 1 | 11 |
| Mahadas et al. (2015) | 0 | 1 | 1 | 0 | 0 | 1 | NR | NR | 0 | 1 | 0 | 1 | 1 | 0 | 6 |
| Martin et al. (2014) | 1 | 1 | 1 | 1 | 0 | 1 | NR | NR | 1 | 1 | 1 | 1 | 1 | 0 | 10 |
| McPherson (1999a) | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 11 |
| McPherson (1999b) | 1 | 1 | 1 | 0 | 0 | 1 | 1 | NR | 1 | 1 | 1 | 1 | 1 | 0 | 10 |
| McPherson (2000) | 1 | 1 | 1 | 0 | 0 | 1 | 1 | NR | 1 | 1 | 1 | 1 | 1 | 0 | 10 |
| McPherson and Kernodle (2007) | 1 | 1 | 1 | 0 | 0 | 1 | 1 | NR | 1 | 1 | 1 | 1 | 1 | 1 | 11 |
| McPherson and Thomas (1989) | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 9 |
| Murphy et al. (2016) | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| Nielsen and McPherson (2001) | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 11 |
| Rowe et al. (2009) | 1 | 1 | 1 | 1 | 1 | 0 | NR | NR | 1 | 1 | 1 | 1 | 1 | 1 | 11 |
| Rowe and McKenna (2001) | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 11 |
| Shim et al. (2005) | 1 | 1 | 1 | 0 | 0 | 1 | NR | NR | 1 | 1 | 1 | 1 | 1 | 0 | 9 |
| Shim et al. (2005) | 1 | 1 | 1 | 0 | 0 | 0 | NR | NR | 1 | 1 | 0 | 1 | 0 | 0 | 6 |
| Singer et al. (1996) | 1 | 1 | 1 | 0 | 1 | 0 | NR | NR | 1 | 1 | 1 | 1 | 0 | 0 | 8 |
| Smeeton and Huys (2011) | 1 | 1 | 1 | 1 | 0 | 1 | NR | NR | 1 | 1 | 0 | 1 | 1 | 0 | 9 |
| Söğüt (2017) | 1 | 1 | 1 | 1 | 0 | 1 | NR | NR | 1 | 1 | 1 | 1 | 1 | 1 | 11 |
| Tenenbaum et al. (1996) | 1 | 1 | 1 | 1 | 0 | 0 | NR | NR | 1 | 1 | 1 | 1 | 1 | 0 | 9 |
| Tenenbaum et al. (2000) | 1 | 1 | 1 | 1 | 1 | 0 | NR | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 10 |
| Vergauwen et al. (2004) | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 11 |
| Vergauwen et al. (1998) | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 10 |
| Williams et al. (2009) | 1 | 1 | 1 | 1 | 0 | 1 | NR | NR | 1 | 1 | 1 | 1 | 0 | 0 | 9 |
| Williams et al. (2002) | 1 | 1 | 1 | 1 | 0 | 1 | NR | NR | 1 | 1 | 1 | 1 | 1 | 1 | 11 |

*Only first author is mentioned, except for the author Shim; NR = not registered; ^a1 = meet criteria; 0 = does not meet criteria; ^b(1) Was the aim of the study stated clearly? (2) Was relevant background literature reviewed? (3) Was the design appropriate for the research question? (4) Was the sample described in detail? (5) Was sample size justified? (6) Was informed consent obtained? (7) Were the outcome measures reliable? (8) Were the outcome measures valid? (9) Were results reported in terms of statistical significance? (10) Were the analysis methods appropriate for the research design? (11) Was practical importance reported? (12) Were conclusions appropriate given the study findings? (13) Are there any implications for future research given the results of the study? (14) Were limitations of the study acknowledged and described by the authors?

No evidence was found for differences in serve success rates or serve efficiency in relation to performance levels (Girard et al., 2005; Martin et al., 2014).

Twenty-seven studies belonging to the tactical skills category were included in the review. Seven of these studies were of high methodological quality, eighteen were of good methodological quality and two studies were of low methodological quality. There was strong evidence that advanced players have greater and more elaborate tactical knowledge than players with lower performance levels (García-González, Iglesias, Moreno, Moreno, & Del Villar, 2012; McPherson, 1999a, 2000; McPherson & Kernodle, 2007). There was also evidence that superior visual search strategies are deployed by players with higher performance levels compared with those in the intermediate or novice categories. Specifically, high-performing players required less time to predict the directions of serves or groundstrokes (Balser et al., 2014; Cañal-Bruland, van Ginneken, van der Meer, & Williams, 2011; Goulet, Bard, & Fleury, 1989; Jackson & Mogan, 2007; Loffing & Hagemann, 2014;

Loffing, Wilkes, & Hagemann, 2011; Mahadas et al., 2015; Singer, Cauraugh, Chen, Steinberg, & Frehlich, 1996; Tenenbaum, Levy-Kolker, Sade, Liebermann, & Lidor, 1996; Williams et al., 2002).

The studies provided strong evidence that professionals and advanced players are able to predict final ball locations or the performed stroke types more accurately compared with novices (Balser et al., 2014; Farrow, Abernethy, & Jackson, 2005; Goulet et al., 1989; Huys, Smeeton, Hodges, Beek, & Williams, 2008; Jackson & Mogan, 2007; Loffing & Hagemann, 2014; Loffing et al., 2011; Rowe, Horswill, Kronvall-Parkinson, Poulter, & McKenna, 2009; Shim, Carlton, Chow, & Chae, 2005; Shim, Miller, & Lutz, 2005; Singer et al., 1996; Tenenbaum et al., 1996; Tenenbaum, Sar-El, & Bar-Eli, 2000). However, there was weak evidence for the differentiation of professionals and advanced players, advanced players and intermediate players and intermediate players and novices based on players' predictions of final ball locations (Cañal-Bruland et al., 2011; Cocks et al., 2016; Farrow & Abernethy, 2003; Farrow et al., 2005;

Table 2. Characteristics of the 40 studies reviewed measuring technical and/or tactical skills in players with different levels of performance.

| Author | Sample size, sex | Age (years) \pm SD | Level of performance, playing experience (years), number of participants | Measure(s) of skill(s) | Results |
|--------------------------------------|------------------|--|--|--|---|
| Technical and tactical skills | | | | | |
| Del Villar et al. (2007) | 12, male | 21.7 \pm 1.3 12.3 \pm 0.8 | A, 14.7 \pm 1.8, (n = 6) N, 3.8 \pm 1.0, (n = 6) | Observational instrument to measure decision-making and outcome of serves and groundstrokes during real match situation | A \approx N successful control of serve and groundstroke A > N decision-making and forceful outcome of serve and groundstroke |
| McPherson and Thomas (1989) | 40, male | 11.1 \pm 0.4 11.1 \pm 0.7 13.1 \pm 0.6 12.9 \pm 0.7 | A, (n = 10) N, (n = 10) A, (n = 10) N, (n = 10) | Skill test, observational instrument to measure decision-making and outcome of serves and groundstrokes including verbal reports during real match situation | A > N serve and groundstroke performance A > N decision-making and forceful outcome of serve and groundstroke A > N declarative and procedural knowledge |
| McPherson (1999a) | 12, female | 19–22 18–22 | A, 3.2, (n = 6) N, 0.2, (n = 6) | Observational instrument to measure decision-making and outcome of serves and groundstrokes including verbal reports during real match situation | A > N serve and groundstroke performance A > N decision-making and forceful outcome of serve and groundstroke A \approx N total and variety of goal concepts A > N more total and variety of condition, action and do concepts A \approx N total regulatory concepts A > N double concepts A \approx N single and triple concepts |
| Nielsen and McPherson (2001) | 12, male | 27.3 22.6 | A, 17.3 \pm 4.9, (n = 6) N, 5.3 \pm 2.7, (n = 6) | Observational instrument to measure decision-making and outcome of serves and groundstrokes during real match situation | A \approx N successful control of serve A > N successful control of groundstroke, decision-making, forceful outcome of serve and groundstroke |
| Technical skills | | | | | |
| Girard et al. (2005) | 32, male | 23.2 \pm 2.9 18.8 \pm 4.6 21.7 \pm 2.1 | A, 14.9 \pm 2.8, (n = 15) I, 6.9 \pm 3.8, (n = 10) N, 0.9 \pm 1.1, (n = 7) | Serve test | A \approx I \approx N serve success rate A > I + N peak ball velocity groundstroke |
| Girard et al. (2007) | 30, male | 21.3 \pm 3.8 | A, 14.9 \pm 2.8, (n = 13) I, 6.9 \pm 3.8, (n = 10) N, 0.9 \pm 1.1, (n = 7) | Serve test | A > I > N peak ball velocity serve |
| Kolman et al. (2017) | 32, male | 13.6 \pm 0.5 13.2 \pm 0.5 | A, 8.8 \pm 1.6 (n = 15) I, 7.1 \pm 1.4 (n = 17) | Groundstroke test (D4T) | A > I peak ball velocity groundstroke, ball accuracy, percentage errors |
| Landlinger et al. (2012) | 13, male | 23.0 \pm 2.3 16.3 \pm 0.5 | P, (n = 6) A, (n = 7) | Groundstroke test | P \approx A strokes inside target area P < A strokes outside court P \approx A strokes in the net P > A peak ball velocity groundstroke P \approx A ball accuracy |
| Lyons et al. (2013) | 30, male/female | 19.5 \pm 3.0 24.9 \pm 9.6 | A, (n = 13) N, (n = 17) | Groundstroke test (mLTST) | A > N ball accuracy and consistency A < N strokes outside court |
| Martin et al. (2014) | 18, male | 25.5 \pm 4.3 25.3 \pm 7.3 | P, (n = 11) A, (n = 7) | Serve test | P > A peak ball velocity serve P > A serve efficiency |
| Söğüt (2017) | 35, male/female | 12.7 \pm 1.1 12.9 \pm 1.5 | A, 6.2 \pm 1.1 (n = 15) I, 5.0 \pm 1.3 (n = 20) | Serve test | A > I peak ball velocity serve |

(Continued)

Table 2. (Continued).

| Author | Sample size, sex | Age (years) \pm SD | Level of performance, playing experience (years), number of participants | Measure(s) of skill(s) | Results |
|-------------------------|------------------|----------------------------------|--|---|---|
| Vergauwen et al. (2004) | 23, male | 12.7 \pm 0.7 | A, 3–4, (n = 7) I, 2–3, (n = 9) N, 0, (n = 7) | Groundstroke test (ForeGround) | A + I > N success rate, peak ball velocity, ball accuracy baseline and sideline, VP, VPS A > I success rate, peak ball velocity, ball accuracy sidelining, VP, VPS A \approx I ball accuracy longitudinal I > N, 62% success rate, 34% ball velocity, 19% ball accuracy baseline, 14% ball accuracy sideline, 73% VP, 367% VPS. A > I, 19% success rate, 17% peak ball velocity, 14% ball accuracy sideline, 66% VP, 93% VPS Down the center 1 st serve P \approx A percentage errors, peak ball velocity, ball accuracy and VPE index P > A VP index Wide 1 st serve P \approx A percentage errors, ball accuracy sideline, VP index, and VPE index P > A peak ball velocity and ball accuracy service line Down the center 2 nd serve P < A percentage errors P \approx A peak ball velocity, VP index, and ball accuracy sideline P > A ball accuracy service line, and VPE index Wide 2 nd serve P < A percentage errors P \approx A peak ball velocity, ball accuracy, and VP index P > A VPE index Neutral situation P < A percentage errors, and ball accuracy sideline P > A peak ball velocity, VP index, and VPE index P \approx A ball accuracy baseline Defensive situation P < A percentage errors P \approx A peak ball velocity, ball accuracy, and VP index P > A VPE index Offensive situation P < A percentage errors P \approx A peak ball velocity, ball accuracy sideline, and VP index P > A ball accuracy baseline |
| Vergauwen et al. (1998) | 27, male | 21.0 \pm 1.0 | P, 24 \pm 4, (n = 7) A, 10 \pm 1, (n = 20) | Groundstroke and serve test (LTPT) | |
| Tactical skills | | | | | |
| Balser et al. (2014) | 32, male/female | 22.6 \pm 5.1 25.4 \pm 3.9 | A, 16 \pm 5.7, (n = 16) N, 0.2 \pm 0.5, (n = 16) | Video-clips were used to predict the direction of the ball (spatial anticipation) and to decide forehand or backhand stroke to observed action (motor anticipation) | A > N response accuracy in motor and spatial condition A \approx N mean response time in motor and spatial condition Non-significant interaction (level of performance \times response condition) for response accuracy A > I response accuracy Non-significant interaction (level of performance \times information available) for response accuracy |
| Buckolz et al. (1988) | 44, male/female | 15–16 | A, (n = 21) I, (n = 23) | Temporal occlusion paradigm was used to examine the type of passing shot performed | |

(Continued)

Table 2. (Continued).

| Author | Sample size, sex | Age (years) \pm SD | Level of performance, playing experience (years), number of participants | Measure(s) of skill(s) | Results |
|-------------------------------|--|---|---|---|--|
| Cañal-Bruland et al. (2011) | 40 | 25.7 \pm 10.2 33.3 \pm 20.7 | A, (n = 19) I, (n = 21) | Temporal occlusion paradigm was used for body (parts) to examine spatiotemporal characteristics of visual information pick-up when anticipating groundstroke direction | A > I response accuracy in control, legs, hips, trunk, arms manipulation A < I response accuracy in arm-racket manipulation Non-significant interaction (level of performance \times temporal occlusion) for response accuracy A > I response accuracy A < I directional errors A \approx I depth errors Non-significant interaction (level of performance \times contextual condition) for response accuracy |
| Cocks et al. (2016) | 24, male | 20.7 \pm 2.4 21.8 \pm 3.5 | A, 10.5 \pm 4.4, (n = 12) I, 7.8 \pm 7.3, (n = 12) | Temporal occlusion paradigm was used at racket-ball contact to examine spatiotemporal characteristics of visual information pick-up when anticipating groundstroke direction | |
| Farrow and Abernethy (2003) | Exp. 1: 27, male/female Exp. 2: 29, male/female | Exp. 1: 19.7 22.3 \pm 2.65 Exp. 2: 17.6 19.8 | Exp. 1: A, 11.4, (n = 11) N, (n = 16) Exp. 2: A, 10.2, (n = 15) I, 5.8, (n = 14) | Exp. 1: Temporal occlusion paradigm with moving window condition was used to examine verbal predictions of stroke direction Exp. 2: Liquid crystal occluding in combination with temporal occlusion paradigm with moving window condition was used to examine real movement responses to serves on court | Exp. 1: A \approx N response accuracy Non-significant interaction (level of performance \times display condition), (level of performance \times temporal occlusion) and (level of performance \times display condition \times temporal occlusion) for response accuracy Exp. 2: A \approx I response accuracy Significant interaction (level of performance \times display condition) and (level of performance \times display condition \times temporal occlusion) for response accuracy |
| Farrow et al. (2005) | 16 | 17.5 19.6 | A, 9, (n = 8) I, 5.8, (n = 8) | Temporal occlusion paradigm was used to examine the direction of serves with a movement based response and a verbal response | A > I response accuracy in movement based response A \approx I response accuracy in verbal response Significant interaction (level of performance \times type of perception-action coupling) for response accuracy Non-significant interaction (level of performance \times response mode \times temporal occlusion) for response accuracy A > N in total and variety of condition and regulatory concepts. A > N in total action concepts. A \approx N in variety of action concepts. A \approx N in total and variety of goal concepts. A > N concept linkages. |
| García-González et al. (2012) | 12 | 16.1 \pm 2.3 16.3 \pm 2.3 | A, (n = 6) I, (n = 6) | Interview procedure including verbal reports were used to examine knowledge representation | Exp. 1: A > N response accuracy A > N number of fixations A > N organize search more frequently around head and shoulder/trunk complex Significant interaction (level of performance \times type of exchange) for scan paths Significant interaction (level of performance \times server's handedness), (level of performance \times type of serve) and (level of performance \times server's handedness \times type of serve) for response accuracy Significant interaction (level of performance \times phase of serve) for number of fixations Exp. 2: A > N response accuracy A > N decision-time Significant interaction (level of performance \times situation) for response accuracy Significant interaction (level of performance \times situation) for decision time |
| Goulet et al. (1989) | Exp. 1: 29, male/female Exp. 2: 20, male/female | Exp. 1: 22.3 21.6 Exp. 2: 22.1 21.2 | Exp. 1: A, (n = 15) N, (n = 14) Exp. 2: A, (n = 10) N, (n = 10) | Exp. 1 + 2: Temporal occlusion paradigm was used to predict the type of serve (flat, topspin, slice), number and source of eye fixations | |

(Continued)

Table 2. (Continued).

| Author | Sample size, sex | Age (years) ± SD | Level of performance, playing experience (years), number of participants | Measure(s) of skill(s) | Results |
|-------------------------------|------------------|---------------------------|--|---|--|
| Huys et al. (2008) | Exp. 1: 25 | Exp. 1: 26.6 ± 11.1 | Exp. 1: A, (n = 13) | Exp. 1 + 2: Stick figures were used to examine anticipation accuracy of groundstroke direction | Exp. 1: A > N response accuracy Non-significant interaction (level of performance × situation) for response accuracy Exp. 2A+2B: A ≈ N response accuracy |
| | Exp. 2A: 28 | 34.0 ± 11.6 | I, (n = 12) | | |
| | Exp. 2B: 28 | 22.1 ± 4.5 | A, (n = 14) | | |
| | | 39.9 ± 11.7 | I, (n = 14) | | |
| Jackson and Mogan (2007) | | Exp. 2B: 26.8 ± 11.4 | A, (n = 14) | Temporal occlusion paradigm was used to examine the ability to predict direction tennis serve by viewing video footage that was occluded on the last frame before racquet-ball contact. Verbal reports were used to examine visual information processing | A > N response accuracy A ≈ I response accuracy I ≈ N response accuracy A > N amount of information sources reported in verbal report A ≈ I amount of information sources reported in verbal report I ≈ N amount of information sources reported in verbal report Non-significant interaction (level of performance × occlusion condition) for response accuracy A > N response accuracy A ≈ N information pick-up from early to late occlusion conditions A > N expect more cross-court groundstrokes A > N more varied expectations as a function of stroke position across temporal occlusion conditions Non-significant interaction (level of performance × temporal occlusion) and (level of performance × shot position) for response accuracy A > N response accuracy A > N perceptual sensitivity Non-significant interaction (level of performance × display condition) for response accuracy and perceptual sensitivity I > N earlier eye movement initiation I ≈ N head movement initiation A > N plans concerning higher level goals. A ≈ N total reactive, literal and concentration concepts A > N more total and variety of condition, goal, action and do concepts A ≈ N total and variety of regulatory concepts A > N higher levels of tactical plans. A > N in total and variety of condition, action and do concepts A ≈ N in total and variety of goal concepts. A > N concept linkages A > N total and variety condition concepts A ≈ N total and variety action and goal concepts A < N do concepts A ≈ N regulatory concepts A > N detailed conditions and actions A > N total concept linkages A ≈ N total connections |
| | | 38.3 ± 10.8 | I, (n = 14) | | |
| | 37 | 20.4 ± 1.9 | A, 9.6 ± 2.5, (n = 13) | | |
| | | 20.7 ± 1.7 | I, 8.9 ± 2.4, (n = 13) | | |
| Loffing and Hagemann (2014) | 52, male | 21.6 ± 3.1 | N, 0.6 ± 0.6, (n = 11) | Temporal occlusion paradigm was used in a video-based experiment with point-light condition to examine the anticipation of groundstroke direction | |
| | | 24.7 ± 4.3 26.0 ± 3.8 | A, 16.7 ± 4.7, (n = 26) N, (n = 26) | Video-based experiment with point-light condition was used to anticipate groundstroke direction | |
| Loffing et al. (2011) | 48, male | 26 ± 6.04 26.17 ± 3.84 | A, 17.9 ± 5.7 N | Biosensors and eye sensors were used to measure eye and head motions | |
| Mahadas et al. (2015) | 4, male/female | 19–22 | I, 5, (n = 2) N, 1, (n = 2) | Verbal reports during real match situation were used to examine planning strategies | |
| McPherson (1999b) | 12, female | 19–22 18–22 | A N | | |
| McPherson (2000) | 12, female | 19–22 18–22 | A, (n = 6) N, 0.2, (n = 6) | Interview procedure including verbal reports were used to examine tactical problem representation | |
| McPherson and Kernodle (2007) | 12, male | 27.3 22.6 | A, 17.3 ± 4.9, (n = 6) N, 5.3 ± 2.7, (n = 6) | Verbal reports during real match situation were used to examine problem representations | |

(Continued)

Table 2. (Continued).

| Author | Sample size, sex | Age (years) \pm SD | Level of performance, playing experience (years), number of participants | Measure(s) of skill(s) | Results |
|-------------------------|------------------------------------|--|--|--|--|
| Rowe and McKenna (2001) | Exp. 1 + 2: 36, male Exp. 3: 32 | Exp. 1 + 2: 21.6 \pm 9.0 20.2 \pm 1.5 19.5 \pm 1.5 Exp. 3: 20.8 \pm 1.8 20.5 \pm 3.2 | Exp. 1 + 2: A, 9.0 \pm 5.5, (n = 8) I, 6.0 \pm 3.5, (n = 14) N, 1.6 \pm 1.7, (n = 18) Exp. 3: A, 11.5 \pm 3.0, (n = 16) N, 1.4 \pm 1.4, (n = 16) | Exp. 1: Video-based simulation test was used to examine anticipatory skill Exp. 2: Real-world footage was used to examine anticipatory skill Exp. 3: Video-test with dual-task condition was used to examine anticipatory skills | Exp. 1: A > I + N for response latency I \approx N response latency A \approx I \approx N reaction time Exp. 2: A > N for response latency Exp. 3: A < N response time under single and dual task condition Significant interaction (level of performance \times task condition) for response time Non-significant interaction (level of performance \times task) for missed target shots |
| Murphy et al. (2016) | Exp. 1 36, male Exp. 2 20, male | Exp. 1 24.0 \pm 5.6 24.1 \pm 4.7 Exp. 2 28.6 \pm 4.7 23.7 \pm 4.4 | Exp. 1 P, 17.8 \pm 5.5 (n = 16) I, 7.0 \pm 4.8 (n = 20) Exp. 2 P, 22.0 \pm 5.3 (n = 10) I, 3.8 \pm 3.9 (n = 10) | Exp. 1 Video-based experiment with normal and animated videos was used to examine the anticipation of groundstroke direction and depth Exp. 2 Video-based experiment with animated videos was used to examine the anticipation of groundstroke direction and depth Verbal reports and visual search data were used to examine visual information | Exp. 1 P > I response accuracy for direction, depth and combination Significant interaction (level of performance \times display) for response accuracy Exp. 2 P > I response accuracy for depth and combination, evaluation statements, different keywords, ball flight fixations P \approx I response accuracy direction, number of words verbal report, prediction statements, number of fixations, fixation duration Non-significant interaction (level of performance \times statement type) and (level of performance \times keyword type) A > N response accuracy Significant interaction (level of performance \times shot type \times temporal occlusion) for response accuracy A > N response accuracy A \approx N response delay time Non-significant interaction (level of performance \times shot type \times display) for response accuracy A > N overall prediction accuracy A > N response accuracy 2D and 3D live conditions A \approx N response accuracy point-light display Significant interaction (level of performance \times shot type \times display) for response accuracy A < N number of fixations and total duration time towards head A < N time to make prediction about serve and groundstroke A > N response accuracy type and direction serve and groundstroke A < N reaction and movement time Significant interaction (level of performance \times body area) for viewing time I > N response accuracy Non-significant interaction (level of performance \times condition) for response accuracy |
| Rowe et al. (2009) | 80, male/female | 24.7 \pm 9.5 22.3 \pm 5.2 | A N | Temporal occlusion paradigm was used to examine the anticipation of disguised and non-disguised groundstroke direction | |
| Shim et al. (2005) | 28, male/female | A, (n = 14) N, (n = 14) | | Temporal occlusion paradigm was used for body (parts) to examine the anticipation of groundstroke type and direction | |
| Shim et al. (2005) | 25, male/female | 18–35 20–34 | A, (n = 13) N, (n = 12) | Video-based experiment with point-light, full-sized 2D and 3D live conditions was used to examine the anticipation of groundstroke type and direction | |
| Singer et al. (1996) | 60, male/female | A N | | Visual search and anticipation task was used to examine visual tracking, type and direction of serve, direction of groundstrokes, reaction time and movement time | |
| Smeeton and Huys (2011) | 34 | 22.7 \pm 3.5 22.2 \pm 3.4 | I, (n = 15) N, (n = 19) | Video-based experiment with point-light condition was used to examine the anticipation of groundstroke direction | |

(Continued)

Table 2. (Continued).

| Author | Sample size, sex | Age (years) ± SD | Level of performance, playing experience (years), number of participants | Measure(s) of skill(s) | Results |
|-------------------------|------------------|--------------------------|--|---|---|
| Tenenbaum et al. (1996) | 45, male | 22.2 ± 3.5 13.0 ± 2.7 | P, 12.4 ± 2.3, (n = 15) I, 4.4 ± 1.7, (n = 15) | Temporal occlusion paradigm in a video-based experiment was used to examine the anticipation of the final ball landing location | P > I > N response accuracy Significant interaction (level of performance × temporal occlusion) for response accuracy |
| Tenenbaum et al. (2000) | 80, male | 11.0 ± 1.2 8–18+ | N, 1.1 ± 0.6, (n = 15) A, 2.1–12.4, (n = 40) N, 2.1–12.4, (n = 40) | Temporal occlusion paradigm in a video-based experiment was used to examine the anticipation of the final ball landing location | A > N response accuracy Non-significant interaction (level of performance × exposure duration) for response accuracy |
| Williams et al. (2009) | 24 | 19.3 ± 1.2 21.0 ± 1.7 | A, 10.2 ± 3.6 I, 3.8 ± 1.0 | Video-based experiment using stick figure clips was used to examine groundstroke direction | A > I response accuracy Significant interaction (level of performance × body area) for response accuracy |
| Williams et al. (2002) | 16, male | 23.0 ± 7.3 27.2 ± 4.4 | A, 11.9 ± 4.7, (n = 8) I, 3.8 ± 1.0, (n = 8) | Temporal occlusion paradigm in a video-based experiment was used to examine movement-based response and visual information processing | A > I quicker response time A ≈ I response accuracy A < I time fixating on racket A ≈ I number of locations fixed per trial, number of fixations per trial, mean fixation duration A > I successive fixations within and between the head-shoulder and trunk-hip regions Significant interaction (level of performance × body area) for viewing time |

A = advanced players; Exp = experiment; I = intermediates; LTPT = Leuven Tennis Performance Test; mLTST = modified Loughborough Tennis Skill Test; N = novices; P = professionals; VP = velocity-precision; VPE = velocity-precision-error; VPS = velocity-precision-success.

Jackson & Mogan, 2007; Murphy et al., 2016; Smeeton & Huys, 2011; Williams, Huys, Cañal-Bruland, & Hagemann, 2009; Williams et al., 2002). Six out of the nine studies revealed differences between professionals and advanced players, advanced players and intermediate players or intermediate players and novices (Buckolz, Prapavesis, & Fairs, 1988; Cañal-Bruland et al., 2011; Cocks et al., 2016; Murphy et al., 2016; Smeeton & Huys, 2011; Williams et al., 2009), whereas three studies did not find any differences between players whose performance levels differed (Farrow et al., 2005; Jackson & Mogan, 2007; Williams et al., 2002). One study revealed differences between advanced and intermediate players in their movement-based responses but not in their verbal responses (Farrow & Abernethy, 2003).

Four of the studies included in the review examined both technical and tactical skills (Del Villar, González, Iglesias, Moreno, & Cervelló, 2007; McPherson, 1999b; McPherson & Thomas, 1989; Nielsen & McPherson, 2001). Two studies were deemed to be of high methodological quality, whereas the other two studies were of good methodological quality. There was strong evidence that advanced players outscored novices in their serve and groundstroke performances (i.e., technical skills) and in the quality of their decision making (Del Villar et al., 2007; McPherson, 1999a; McPherson & Thomas, 1989; Nielsen & McPherson, 2001). However, there was weak evidence that advanced players outscored novices in terms of their demonstrated tactical knowledge (McPherson, 1999a; McPherson & Thomas, 1989).

Discussion

The aim of this review was to provide an overview of outcome measures and instruments identified in the literature for examining technical and tactical skills in tennis in relation to performance levels and to provide recommendations for the analysis of these skills in tennis performance. Studies in which only technical skills were measured revealed that ball velocity distinguished high-performing players from lower-performing players. However, there was weak evidence that advanced players demonstrated greater accuracy in their ball placement compared with their counterparts with less advanced skills. The finding that advanced players outscored players whose performance levels were lower in terms of ball velocity is supported by the results of studies done on other sports, such as handball and volleyball. These studies showed that highly skilled players produced higher ball velocities than their less skilled counterparts (Laffaye, Debanne, & Choukou, 2012). Although few studies have assessed the relationship between ball accuracy and performance level, it seems that differences only exist between advanced and intermediate players and between advanced players and novices (Lyons et al., 2013; Vergauwen et al., 2004). No differences were found between professionals and advanced players (Landlinger et al., 2012). However, it is noteworthy that the studies applied different methodologies (relating to size and target areas). Consequently, it is difficult to draw definitive conclusions about the relationship between ball accuracy and performance level. Studies done on other sports have revealed differences in ball accuracy that exist not only

between experts and novices (Beilock, Bertenthal, McCoy, & Carr, 2004) but also between players whose performance levels are more homogeneous (Huijgen, Elferink-Gemser, Ali, & Visscher, 2013). Two studies that assessed technical skills revealed that young players with more experience scored higher than less experienced players for ball velocity and ball accuracy, and their success rates were higher than those of players with less experience (Kolman et al., 2017; Vergauwen et al., 2004). However, more research is needed to examine the relationship between ball velocity and accuracy, as these factors appear to be important for future performance levels. According to the speed-accuracy trade-off hypothesis, an increase in the execution time of a movement is required to achieve greater accuracy (Fitts, 1954). A previous study conducted on soccer revealed that top players demonstrated greater accuracy in their ball control, especially under time pressure, compared with lower ranked players (Huijgen et al., 2013). Future studies should focus especially on investigating whether more experienced players are able to maintain accurate strokes under conditions of increasing demands (e.g., speed) in tennis. However, other characteristics such as anthropometry and physiology could affect serve velocity (Kraemer et al., 2003; Perry, Wang, Feldman, Ruth, & Signorile, 2004).

The studies that assessed only tactical skills showed strong evidence that performance levels were differentiated according to decision-making and anticipatory skills, tactical knowledge and visual search strategies. Advanced players make better decisions than novices, possibly because of their acquisition of a greater degree of implicit (unconscious) control (Masters et al., 2008). Implicit processes are organized and occur faster than conscious control processes, because unlike the latter, the application of advanced procedural knowledge does not entail conscious thought (e.g., Masters et al., 2008; Raab, 2003). Implicit processes are therefore independent of working memory (Baddeley, 2003), which explains why experts have sufficient remaining resources to make reasonable decisions. By contrast, explicit processes depend on working memory for the retrieval of consciously accessible (declarative) knowledge (Maxwell, Masters, & Eves, 2003). Because novices' performances are more dependent on explicit processes and working memory, the demands of a complex task are likely to overload them and reduce their performance.

Advanced players were found to be faster and more accurate in their anticipation of the directions of their opponents' strokes than players whose performance levels were lower. This finding is supported by those of a soccer study, which showed that advanced players' predictions of the directions of penalty kicks were more accurate than those of novices (Savelsbergh, Williams, Kamp, & Ward, 2002). Advanced players use more selective visual search patterns than do novices, as reflected by the higher response accuracy in anticipatory tasks reported in several studies (Balser et al., 2014; Buckolz et al., 1988; Cocks et al., 2016; Farrow & Abernethy, 2003; Goulet et al., 1989; Jackson & Mogan, 2007; Loffing & Hagemann, 2014; Loffing et al., 2011; Murphy et al., 2016; Rowe et al., 2009; Shim, Carlton, et al., 2005; Shim, Miller, et al., 2005; Singer et al., 1996; Smeeton & Huys, 2011;

Tenenbaum et al., 1996, 2000; Williams et al., 2009). Moreover, Farrow and Reid (2012) showed that the anticipatory capability of players is also dependent on age, with older players demonstrating more advanced anticipatory skills than younger players. Anticipatory tasks entail mostly temporal occlusion paradigms, but point-light displays and stick-figure conditions are used as well to examine these abilities. Singer et al. (1996) found that whereas advanced players focused their attention on the wrist and shoulder of the opponent when anticipating the ball's direction, novices focused more on the opponent's head and non-dominant side. It seems that advanced players focus on relevant proximal cues (e.g., those associated with the opponent's trunk, arm and hips), whereas novices focus more on distal cues like the opponent's head (Goulet et al., 1989; Singer et al., 1996). However, tennis performance entails multidimensional performance characteristics that include technical and tactical skills among others. This review did not examine other performance characteristics, such as perception, that may also be relevant, particularly in relation to technical and tactical skills. Thus, future studies could explore the importance of perception related to tennis performance.

The instruments identified in this systematic review are important for analysing performance in tennis. Newell's constraints-led approach, which has been applied in performance analysis (Glazier, 2010; Newell, 1986), suggests that sports performance hinges on three sources: the task, the environment and the individual. According to Davids, Button, and Bennett (2008), the key role of coaches and instructors is to manipulate these constraints so that they facilitate players' discovery of functional movement patterns. Constraints can be manipulated in practice through the introduction of instruments. For example, task constraints can be changed by introducing target areas used to measure or improve ball accuracy. However, the instruments identified in this review varied in their practicality.

The interview procedures applied during actual match situations for examining decision-making skills require less experience and materials and could be easily incorporated in practice by coaches and instructors. In addition a radar system and target areas for assessing ball velocity and ball accuracy, respectively, could be easily integrated in practice. However, the use of video-based experiments for measuring anticipatory skills and visual behaviours would be more difficult to incorporate into training, as these require more expertise and resources. Moreover, a point to consider when introducing such instruments to practically monitor and improve anticipatory skills is that implicit learning techniques may be more effective than explicit learning instructions, especially under stressful conditions (Liao & Masters, 2001; Williams et al., 2002). Players could benefit from instructions that direct their attention towards information-rich areas as opposed to specific information cues. They should be instructed to focus solely on the contact zone so that they can discern regularities between the racket and ball orientation for each type of serve (Williams et al., 2002).

For this review, two expert researchers working independently from one another assessed the methodological quality of the studies as accurately as possible using the quality

assessment form developed by Law et al. (1998). It is conceivable that scores might have been slightly different if another form had been used. However, a limitation of this review was that sex and age were not considered in comparisons of performance levels. Therefore, it is difficult to draw definitive conclusions regarding which factors are important for players of different ages and sexes. Very little research has been conducted on technical and tactical skills. In addition, few studies were found that assessed these skills longitudinally or focused on young tennis players. Technical and tactical skills should be measured over time in studies of young players to deepen understanding of the development of these skills.

Thirty-six articles in which technical or tactical skills were separately measured were included in the review. These studies provided insights relating to particular skills that differentiate players with different performance levels. One advantage of conducting separate assessments of technical and tactical skills is that this leads to more knowledge about a specific skill related to the level of performance within a more controllable environment. By contrast, a significant disadvantage of measuring technical or tactical skills in isolation is that this measure is not reflective of actual match play, because a tennis stroke is always executed in a particular context and not in isolation. The tactical possibilities depend on players' technical abilities, given that technical skills both determine and limit players' tactical solutions and decisions. The reverse is also true, as players' technical skills determine tactical possibilities. The performance of a particular stroke (i.e., technical execution) that is most likely to result in winning the point is based on a tactical decision, meaning that these skills should be studied in an integrated way. Future studies should explore the relationship between technical and tactical skills and tennis performance. In addition, further studies should focus on developing a test for the integrated measurement of these skills.

Conclusions

The aim of this review was to provide an overview of outcome measures and instruments identified in the literature for examining technical and tactical skills in tennis in relation to performance levels and to provide recommendations for the analysis of these skills in tennis performance. The results of the studies that measured only technical skills revealed that performance levels were differentiated based on ball velocity. Weak evidence was found for more accurate ball placement by advanced players compared with their less skilled counterparts. The studies that assessed only tactical skills showed strong evidence that players with higher performance levels display superior decision-making and anticipatory skills, more elaborate tactical knowledge and better visual search strategies than players whose performance levels are lower. However, a significant disadvantage of the studies was that they mainly measured technical and tactical skills in isolation. This is a drawback because players' technical skills determine and limit their tactical solutions and decisions (and vice versa); therefore these skills should be studied in an integrated manner. Future studies should explore the relationship between technical and tactical

skills and tennis performance. In addition, they should focus on developing a test that enables these skills to be measured in an integrated manner and is also easy to incorporate in practice.

Disclosure statement

No potential conflict of interest was reported by the authors.

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